the reservoir supercapacitors within the hysteresis band. The released current (e.g., charging current) through the PFM-mode dc-dc converter can offset the leakage current of reservoir supercapacitor. When the charging current is equal to the leakage current, the charger can no longer charge the reservoir supercapacitor. This is called the boundary of leakage offset current ($I_{leak,offset}$). In this sense, the leakage offset current can be obtained at the moment that the leakage energy is equivalent to the charging energy of the reservoir supercapacitor during one cycle.

[0011] There exists a need for new charger designs that have high efficiency during low power supply and low power consumption conditions.

BRIEF SUMMARY OF THE EMBODIMENTS

[0012] Disclosed and claimed herein are methods and devices for supercapacitor charging. One embodiment is directed to a supercapacitor charger including a charge-strapping supercapacitor configured to accumulate energy from a low-power source, and a burst control module configured to release energy accumulated by the charge-strapping supercapacitor, wherein a burst transfer window for releasing energy by the burst control module is controlled by the charge-strapping capacitor. The supercapacitor charger also includes a boost converter configured to charge a reservoir supercapacitor, wherein the boost converter is enabled and disabled by the burst control module based on the burst transfer window.

[0013] In one embodiment, the charge-strapping supercapacitor is between the range of 2 F to 5 F.

[0014] In one embodiment, the charge-strapping supercapacitor includes a charge time based on a leakage current of the reservoir supercapacitor.

[0015] In one embodiment, the burst control module includes a non-inverting comparator configured to provide burst-transfer window control.

[0016] In one embodiment, the burst control module enables the boost converter based on the charge-strapping supercapacitor approaching an upper bound of the burst transfer window and wherein the burst control module disables the boost converter when the voltage of the charge-strapping supercapacitor drops to a lower bound of the burst transfer window.

[0017] In one embodiment, the burst control module turns the boost control on to charge the reservoir supercapacitor at the maximum power point of the low power source.

[0018] In one embodiment, the boost converter is a pulse-frequency modulation (PFM) dc-dc boost converter.

[0019] In one embodiment, the boost converter transfers stored energy of the charge-strapping supercapacitor to the reservoir supercapacitor during the burst transfer window.

[0020] In one embodiment, the burst transfer window is an adjustable burst window.

[0021] In one embodiment, the charge-strapping supercapacitor is arranged in parallel with the boost converter and the reservoir supercapacitor, and wherein the burst controller controls connection of the charge-strapping supercapacitor to the boost converter.

[0022] In one embodiment, the low power source is at least one of a thermoelectric generator, fuel cell, galvanic corrosion source, and photovoltaic cell.

[0023] One embodiment is directed to a supercapacitor charger including a charge-strapping supercapacitor configured to accumulate energy from a low-power source, wherein the charge-strapping supercapacitor includes a charge time based on a leakage current of the reservoir supercapacitor. The supercapacitor charger also includes a burst control module configured to release energy accumulated by the charge-strapping supercapacitor, wherein a burst transfer window for releasing energy by the burst control module is controlled by the charge-strapping capacitor burst control module enables the boost converter based on the charge-strapping supercapacitor approaching an upper bound of the burst transfer window and wherein the burst control module disables the boost converter when the voltage of the charge-strapping supercapacitor drops to a lower bound of the burst transfer window. The supercapacitor charger also includes a boost converter configured to charge a reservoir supercapacitor, wherein the boost converter is a pulse-frequency modulation (PFM) dc-dc boost converter, and wherein the boost converter is enabled and disabled by the burst control module based on the burst transfer window.

[0024] One embodiment is directed to a method of implementing a hysteretic charging scheme supercapacitor charger including controlling hysteresis, optimizing a window size; and controlling a two-stage supercapacitor composition with a pulse-frequency modulation dc-dc boost converter.

[0025] Other aspects, features, and techniques will be apparent to one skilled in the relevant art in view of the following detailed description of the embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] The features, objects, and advantages of the present disclosure will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout and wherein:

[0027] FIG. **1** depicts a typical boost converter schematic;

[0028] FIG. **2**A depicts an equivalent circuit model of supercapacitors;

[0029] FIG. **2**B depicts the relationship between leakage current and voltage of supercapacitors;

[0030] FIG. **3** depicts a block diagram of a supercapacitor charger according to one or more embodiments;

[0031] FIG. **4**A depicts a circuit for implementing hysteresis using a positive feedback according to one or more embodiments;

[0032] FIG. **4**B depicts the transfer curve of the non-inverting comparator with hysteresis according to one or more embodiments;

[0033] FIGS. **5**A and **5**B depict waveforms of reservoir supercapacitor voltage according to one or more embodiments;

[0034] FIG. **6** depicts a comparison of results between conventional continuous charging scheme and hysteretic charging-mode charging scheme according to one or more embodiments;

[0035] FIG. **7** depicts the boundary between charging current and leakage current according to one or more embodiments;

[0036] FIG. **8** depicts a working prototype stage of the hardware architecture for the hysteretic charging-mode boost charger according to one or more embodiments;

[0037] FIG. **9** depicts a process for supercapacitor charging according to one or more embodiments; and

[0038] FIG. **10** depicts determining capacitance of a charge-strapping supercapacitor according to one or more embodiments according to one or more embodiments.